PERCEIVED NEEDS SPACE PROPULSION/POWER APPLICATIONS

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Our next speaker - Sol Gorland - who I believe will be standing in for Larry Diehl will be talking about space propulsion systems.

Larry's new job under the reorganization is now the Director of R&T. He asked me to fill in and present on three different programs. These are: APUs (Auxiliary Power Units) IHPRPT (Integrated High Payoff Rocket Propulsion Technology), that's equivalent on the space side to IHPTET; and ASTP the NASA, that's the national initiative for Advance Space Transportation systems. First I'll go through the APU program.

A while back, Dan Goldin asked our director, since we have a center of excellence in turbomachinery, if he could put a program together on advanced APUs. I am not sure if his reason was to look specifically at space shuttle problems or aeronautics, but we looked at it as a combined program. The objective was to demonstrate advanced technologies that will enable high performance, highly reliable, environmentally friendly auxiliary power units. There are problems for both aircraft and space applications. APUs can run either as stand alone systems or they can provide power for the main engines. They handle many of the mechanical systems on the aircraft which drive the pneumatics and hydraulics. Current commercial systems do use some advanced technology such as foil bearings. They are gear box driven, they use some high temperature materials and they are oil lubricated. We looked at getting rid of some of those systems through the use of direct drive systems which could essentially provide the electric and pneumatic power. On the space side APUs are used on the space shuttle with hydrazine fuel. They will also be used on some Reusable Lunch Vehicle (RLV) programs. The issue right now is that we are looking into switching to hydrogen oxygen systems for the X33 and RLV program. That will be a major change in terms of the propellant materials and handling. These APUs are very similar to the systems on aircraft. On the shuttle they provide power for the hydraulics. The issues that we see currently are; longer life, lower weight, cheaper and are more reliable. On the space side there is an environmental issue when using hydrazine. On the aeronautics side there are concerns about emissions. Aircraft in Sweden which utilize engines with high emissions incur fines every time they land, and APUs are contributors to emissions. Health monitoring is an interesting solution, it was mentioned in several previous presentations today. The technique would be to understand the condition of the engine, take a control action at that time or take a maintenance action as soon as you land aircraft or space shuttle. There is not much you can do on the first launch, but when you come back, make sure you understand what happened so you can implement control strategies for future launches. What we see in the future systems is higher pressures since we are trying to make the APUs smaller. We are also trying to go to direct drive systems which get rid of the gear boxes and the oil systems since those are the components that require maintenance. The bottom line is to reduce maintenance and operating costs. We will probably get into some higher temperature issues. Noncontact bearings will be used in place of ball bearings. These include magnetic bearings, and wave bearings. In the future there could be other kinds of APUs, to provide power such as fly wheels or other power generation concepts. We have not considered these as yet but that is what we see for the future.

Right now the program does not exist. It is only a proposed program. On the space side again, the issue is to get rid of hydrazine propellants and go to something that is a lot easier to work with. Again direct drives and noncontacting bearings a very similar program. We saw parallel efforts but the application was a little different. The motivations for industry is on the aircraft side where there is a higher sales potential, however on the space side there in not as much profit potential. In talking to some of the industry people we felt that on the aero side there are incentives to do some contributory work. There are a lot of cooperative agreements between NASA and industry. On the space side, funding would be primarily from NASA because there are not a lot of other applications. The current status is that these are programs being proposed to NASA Headquarters. On the aero side and on the space side individual proposals will be made to the different program offices at Headquarters. We are trying for funding for the next fiscal year which will be 1998.

The next area is the Integrated High Payoff Rocket Propulsion Technology Program (IHPRPT). There are a lot of people working on this program and it is primarily driven by the Air Force. There are a lot of industry people involved on the teams. This work is being led by Don Dix from the Air Force but there are lead people from NASA Headquarters, Bill Escher and from Marshall, Gary Lyles. They are major players in the steering committee. The seals lead is Jim Cannon at Marshall. Seals fit under the category of propellant management devices. It essentially is a DOD/NASA initiative. The idea is to double the capability in terms of performance of rocket engines by 2010. Later, I have some charts that show specific goals. IHPRPT is responding to a lot of military needs. There are areas of work that they would like to see in a technology program. They want a lot of industry involvement. Some of you may have already been talking to people at the Air Force about this program. They have gone out with what they call PRDAs for work in specific categories. They do not want a system that will continually change. They have firm goals which appear in later slides. These goals are based on the state of the art at the time they planned the program in 1993. The technology in the propellant management devices line includes all the turbomachinery, which is of interest to this group as would the category of energy conversion devices and control systems. This chart displays the major areas in the IHPRT program. The following chart discusses the specific goals of the program. There is a specific one for 2000, 2005 and 2010. Across many of these charts is the concern for operability. Maintainability is a major concern. The system must be easily handled and they do not want to run into problems. A typical issue on the space shuttle is that when they work on the hydrazine system everyone has to evacuate the area, no one else is allowed to work. It completely shuts everything down until they can fix the hydrazine system because of safety problems. That is not what we consider an easily maintained friendly system. The IHPRPT group has received input from industry that the goals are reasonable. Improving ISP by 20% is very difficult, even seconds are hard to come by. For the aero people, ISP is equivalent to SFC. These are the prime goals that are currently being considered, offering some really big challenges.

This last program area, Advanced Space Transportation is a NASA initiative. There is some Air Force involvement but it is primarily run out of Marshall because they are the lead for space transportation. In terms of the reorganization of the NASA centers, Marshall is the space transportation center. LeRC is the technology center of excellence for turbomachinery. We do however contribute to many of the areas in this program. In general, space transportation is what gets us into space and Marshall is going to be the focal point for space issues. Marshall has quite a bit of leeway on how they reprogram their funds for propulsion. I believe the program resources are approximately $20,000,000 and scales up each year. It is a sizable program but it covers a lot of areas. The prime foci are the three categories; low cost reusable propulsion, small launcher technology and space transfer technology. Launch costs are really what limits us, the launch costs are very high. The reason they put the RLV program in place is that typical launch costs are approximately $10,000 per pound to orbit. NASA is trying to get down to $1,000 per pound but even at a $1,000 it may be an issue and that is a sizable reduction in launch cost. Transportation costs at NASA (the cost for launching things into space) is 25% of our budget and reducing those costs are a major issue. The reason you will not find seals specifically written on any of the charts, is because they are looking for higher level cost impacts. Seals do have an effect but it is difficult to say that if I work on a better seal I will get a 25% increase in performance or decrease in cost. It is however a contributor and it is in all of the programs. I believe these programs are still early in their formation. The thought is to be cheaper, faster, safer and smaller, better is also safer.

NASA is considering a program in micro satellites, very small launch vehicles. Teledesic is talking about small communication satellites that blanket the earth and which will need small propulsion systems. I would like to focus on the turbomachinery area. The objective is to put together a plan. This program is still being formed and is relatively new, mostly put together within the past year. The motivation is low costs and the reason is that the turbomachinery is 25% to 30% of the weight and cost. Historical data shows that the space shuttle main engine turbomachinery is what causes most of the problems. The approach that they have taken to put the plan together is mostly Marshall's approach. People have been co-located at Marshall from some of the other centers to work on this program plan. There has also been a lot of input from industry. There are Marshall S&E (Science & Engineering) and PD (Program Development) groups working on the plan. They have looked at many programs, have reviewed IHPRPT and are trying to put together a cohesive plan. A draft plan has been presented to Goldin. I believe it will be NASA's future plan for space transportation. We want to enable this whole payload transportation area using high performance to revitalize the Earth to Orbit propulsion area. We are also considering air breathing combined cycle type systems. NASA will be changing how we do business in space and make revolutionary changes rather than incremental changes.

Low cost orbit transfer is an upper stage program which includes space and exploration. That is where we start looking into areas such as nuclearthermal propulsion. Upper stages are a challenge in terms of issues such as the radiation environment. Essentially this is a program in the small payload area. They are looking at a lot of smaller engines, a 2,000 lb. This 10,000 lb. Thrust turbo pump. You are going to see turbomachinery, in many of these applications, but the timeline is relatively short. It is a technology program, but their technology view is only three years in order to meet the need for demonstrations. They are not looking at long-term technology. The issue is, "What is the latest thing that is in the market place now, that can be adapted to these programs?" NASA's view, and I do not necessarily agree with it, is that six years is long term. What I am seeing and I happen to be the Lewis point of contact for the X33 program which is expected to lead to the next reasonable launch vehicle, is that to the problems for the current vehicle programs came out of the earth to orbit technology program. That program was the instigating factor which formed this group, about six or seven years ago. But I do not see the next generation of technology program in place, so that the next vehicle program will have potential solutions. The programs now have solutions because we have been working on them for ten years but I am concerned about the next generation of programs. Where will those solutions come from?

This is the chart for the X34, and the X33. I do not know if there was a talk of the X34; that is a program primarily between NASA Marshall and Orbital Sciences. It is essentially to demonstrate a small launch vehicle. I believe currently the X34 does not go to orbit; although the X33 does not go to orbit either. The plan is go to an RLV in the year 2000 or a little later. The first flights are going to be in 1999, and I believe starting in 1999 or 2000, Lockheed Martin, who has the contract will make a decision on its plans for the RLV. The decision will be based on their view of whether it is commercially viable for them to get into the business of operating their own launch service because it is not going to be government sponsored; it will be a completely commercial unit. So, at that time frame, they are going to say, "Can they make money?" They currently have investors who have put money into the X33, which is a cooperative program, and those investors are going to want answers before they put in additional resources for a full blown vehicle. The X33 program is funded at just under a billion dollars for a little over three years and it will only result in a vehicle that demonstrates that it can go to orbit. It does not go to orbit. The program for the RLV would be orbital. There are a lot of new technologies in the X-33. Again, I have to qualify what I mean by new technologies. It's got a lot of new things in it, but it is not a new technology program. It takes the latest things that are available, adapts them, and then flies them. It's being run out of the Lockheed Skunkworks in Palmdale.

The low cost, high efficiency upper stage is primarily a program that Marshall is looking at for orbit transfer. And notice we have also included, lunar components. I believe that represents the exploration area of orbit transfer for the planetary missions. There are a lot of issues in terms of what kind of engine to use here; we are talking about LOX hydrocarbon and LOX hydrogen propellants. There is also a lot of discussion about using in-situ materials; when you start to do that your can run into other problems, including seal problems. One of the concepts, for a Mars mission is looking at, CO or methane as the potential propellant which you can make on the planet from the CO2 in the atmosphere. For methane, you have to bring some hydrogen with you, which is a little more expensive, but you can make CO directly, although you take a little penalty in performance. In the low cost exploration area there is potential work in nuclear thermal propulsion and here you are going to get into all kinds of radiation issues and higher temperatures. Going through the radiation belts may present problems. I do not know what other issues there are but this program is much further out in time, so the technical work will proceed much slower. I do not think that this part of the program is currently funded. In general, all the new programs do address turbomachinery. The issue that I see in terms of the research and technology is that they are looking at pretty much the state-of-the-art. They are looking at what is currently out there; so that they can use it now. The suppliers will have a lot of work and business. Any meeting that I attend, I usually address the issue of , "What are you doing for ten years from now? I know what you are doing for five years from now, because you are using what we have." Any questions? I do not know if I will have the answers..

Q. Is there any plan to use a MMS technology if any of these new turbomachinery systems?

A. That is an interesting technology. Someone else mentioned it one or two talks back. We have looked into it, the concept of putting a rocket engine on a chip, and there are some concepts out there that address that. It is really interesting. Some of the technologies that are involved, include work on seals and bearings. We are talking about, engines that can produce a pound of thrust in a component the size of the button(s) on your shirt. We have seen results of that technology. They have developed combustors that work at that size. They have actually flowed fluid through it and ignited it. There are turbomachinery components that are that size and they are running at hundreds of thousands RPM. An equivalent of 3,000,00 DN. But we're talking small. I mean it's amazing, when you see some of the technology that is out there. It is not five years away; I am not sure that it is ten years away, but I see it coming.

Q. I mean, in the AST program per se, is there any talk of such machines?

A. No! I have a problem with that because they are not looking far enough out, at what is really there.

C. Yes. I agree. It is not here now.

C. I know there are people interested in it; we have gone down to NASA Marshall and talked to them about it. They have an interest, but they do not see it in the next couple years, and neither do we. So we told them we will just keep them abreast of what we are doing. Lewis is a research and technology center, so we try to work on those things. The only trouble we have is trying to get money for it.

PROGRAMS

APU's -- Auxiliary Power Units

IHPRPT -- Integrated High Payoff Rocket Propulsion Technology

ASTP -- Advanced Space Transportation Program

PROPOSED APU PROGRAM

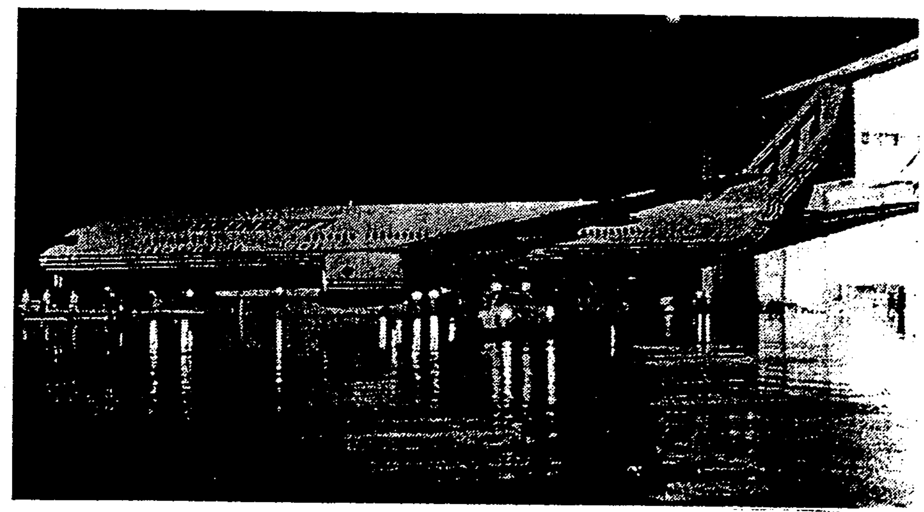
OBJECTIVE

Develop and demonstrate advanced technologies which will enable high performance, highly reliable, environmentally friendly APUs with significant reductions in DOC.

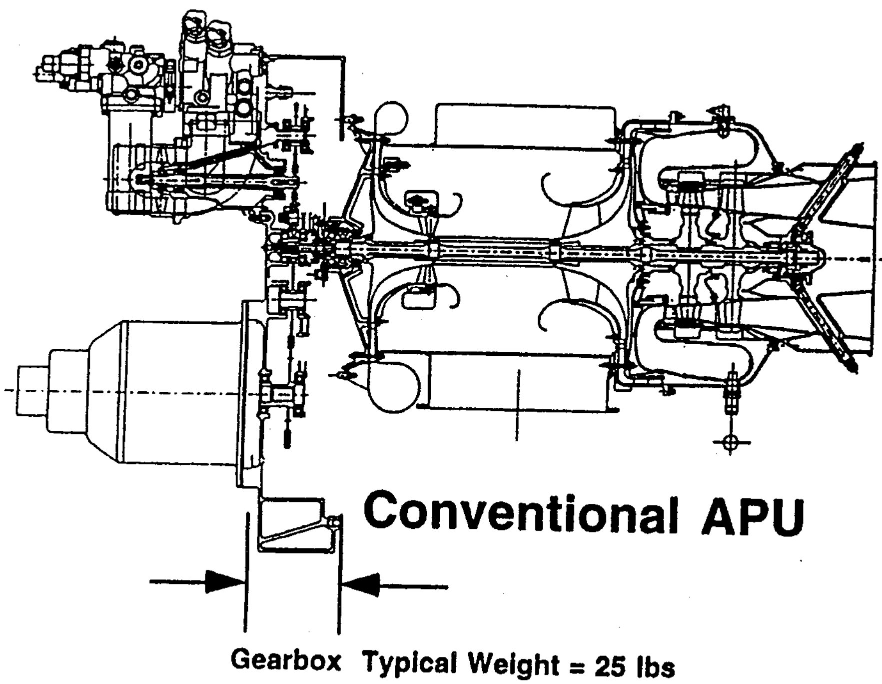
Auxiliary Power Units
(Commercial Aircraft Applications)

APU's Provide:

- Starting power for main engine(s)
- Pneumatic power for environmental control system
- Drive power for other pneumatic and hydraulic systems
- Backup electrical and pneumatic power for in-flight operations
- Electric and pneumatic power for ground operations



Current SOA Systems
Commercial Aeronautical Systems



<u>Function</u>:
Provides electric, pneumatic and/or hydraulic power

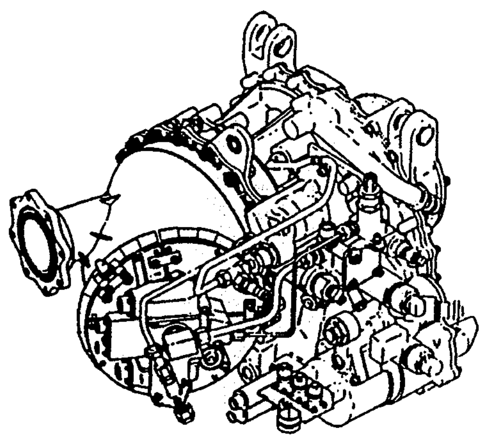
<u>Characteristics</u>

- Foil bearings in recent generations (757, 767, MD-11)
- Gear box driven AC generators
- High temp metal alloys
- Two or three axial turbine
- Oil lubrication system
- Bleed air utilization

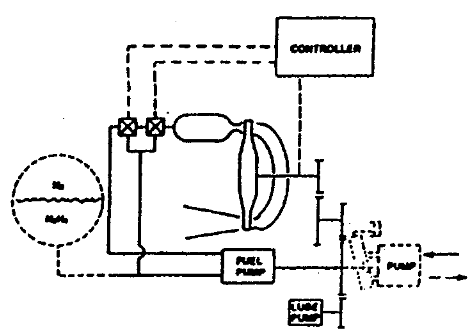
Current SOA Systems

Space Systems (Shuttle APU)

N2H4 APU ISOMETRIC



APU SCHEMATIC



<u>Characteristics</u>

- Hydrazine propellant
- Partial admission metallic turbine
- Gear driven hydraulic pump
- Oil lubrication system
- External cooling system
- Rolling element bearings

<u>Purpose</u>:
Provides hydraulic power

Current Issues in SOA Systems

<u>Aeronautical Systems</u>

Reliability/Certification

Life Cycle Cost

Performance

Environmental Concerns

- Emissions
- Noise

Manufacturing

Controls/Operations

TBO/Health Monitoring

<u>Space Systems</u>

Reliability/Maintainability

Environmental/Hydrazine

Life

Weight/Cost

Efficiency/Performance

Controls/Operations

Future System Characteristics - Aeronautics

Next Generation

- High Pressure Ratio System
- High Work Single Stage Turbine
- Ceramic Turbines and Composite Structures
- Low Emissions/High Altitude Start Combustor
- High Speed Direct Drive
- Non-Contacting Bearings
- High Temperature Electronics and Components
- Integrated Health Management Systems

Future Generation

- Integrated Power and Thermal Management System

Future System Characteristics - Space

Next Generation
- H_2/O_2 propellant
- Integrated subsystems
- Direct drive generator
- Non-contacting bearings
- High turbine tip speeds
- Ceramic and composite materials
- Advanced instrumentation and control system

Future Generation
- Advanced energy storage systems
- Year 2000 materials
- Integrated power system

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DEPARTMENT OF DEFENSE UNITED STATES OF AMERICA

DEPARTMENT OF THE AIR FORCE UNITED STATES OF AMERICA

NAWC NAVAL AIR WARFARE CENTER

NASA

Integrated High Payoff Rocket Propulsion Technology

ARC Atlantic Research Corporation
A unit of Sequa Corporation

THIOKOL
SPACE • DEFENSE • FASTENING SYSTEMS

ROCKET RESEARCH COMPANY
Olin AEROSPACE COMPANY

IHPRPT 2X

ALLIANT TECHSYSTEMS

Rockwell Aerospace
Rocketdyne

GENCORP

TRW

UNITED TECHNOLOGIES CHEMICAL SYSTEMS

KAISER MARQUARDT

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IHPRPT TEAM ORGANIZATION

GOVERNMENT STEERING COMMITTEE

Committee Co-Chairmen- Dr. D. Dix, Mr. G. Lyles

NASA	Army	Navy	Air Force
Mr. W. Escher	Dr. W. Stephens	Mr. D. Siegel	Mr. L. Meyer
Mr. G. Lyles	Dr. O. Ayers	Mr. F. Markarian	LtCol D. Lewis

Mr. J. Chew - Secretariat
Capt. M. Wierschke - Air Force Program Coordinator

Propellants
Navy
Dr. Baldwin

Propellant Management Devices
NASA
Mr. Cannon

Combustion & Energy Conversion
Air Force
Mr. Farner

Control Systems
Navy
Mr. Blashill

Demo
Air Force
Mr. DeGeorge

Thiokol
Mr. S. Robbins

Pratt & Whitney
Mr. G. Cox

Alliant
Dr. D. Fischer

Aerojet
Mr. R. Hankins
Mr. R. Grinsell

Rocketdyne
Mr. G. Havskjold

CSD
Mr. W. Andrepont

ARC
Dr. R. Lynch

TRW
Mr. R. Sackheim

Olin Aerospace
Mr. J. Galbreath

Kaiser Marquardt
Mr. J. Jensen

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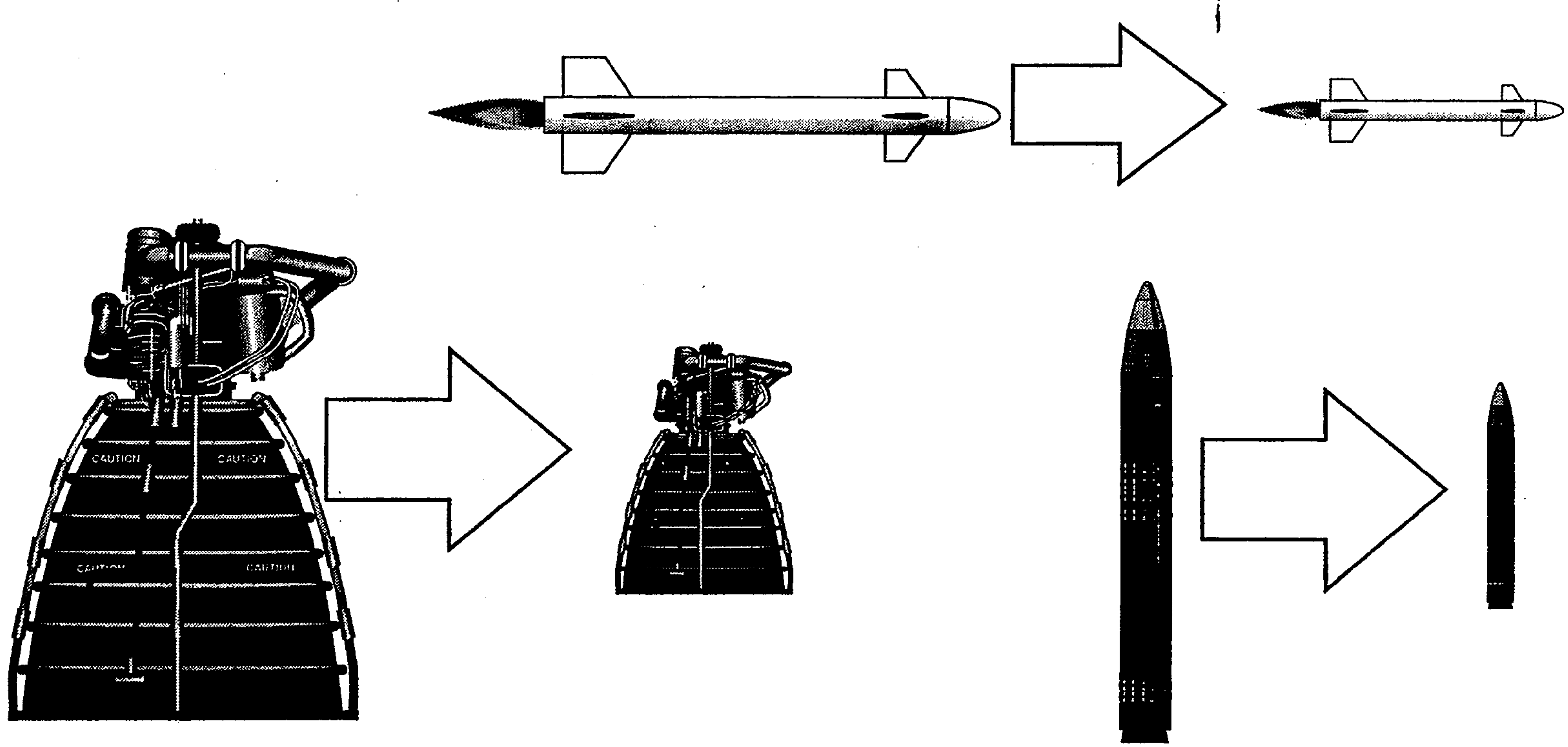
IHPRPT Is ....

A DoD / NASA /Industry Initiative Which Will "Double" Rocket Propulsion Capability by 2010



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IHPRPT Descriptions

- A Structured, Government - Industry Program
  - — Responsive to National Military / Civil / Commercial Needs
  - — Based Upon a Co-Developing Technology Plan
  - — The Framework for Organizing and Guiding S&T Investments
  - — An Integral Part of a DoD Technical Area Plan (TAP)
- A Technology Driven Program
  - — Not Subject to “System-of-the-Year” Whims
- A Goal Oriented Program
  - — Firm, Challenging but Attainable Goals
  - — Time Phased and Measurable
  - — Based on 1993 Propulsion Capabilities
- Attainment of Goals Will Provide Large System Payoffs
- Key Demonstrations Used as Metric

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IHPRPT Major Technology Areas

(Component Technology Areas)

- **Propellants**
  (Solid, Liquid, Gels, Liners)
- **Propellant Management Devices**
  (Tanks, Feed Systems, Bladder, Turbomachinery, Thermal Protection System, Cases, Pressurization Systems, Insulation)
- **Combustion and Energy Conversion Devices**
  (Injector, Nozzles- Liquid, Solid, Igniter, Combustion Chamber, Gas Generator, Preburner)
- **Control Systems**
  (Health Monitoring, Actuators, Controller, Ordnance Devices, Valves- Hot, Cold, Divert, Propellant, etc...)

→ **Demonstrators**
(Test Beds, Subscale Systems, Combustion Devices)

↓

Systems Applications

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IHPRPT GOALS

Boost and Orbit Transfer Propulsion	2000	2005	2010
• Reduce Stage Failure Rate	25%	50%	75%
• Improve Mass Fraction (Solids)	15%	25%	35%
• Improve ISP (sec)	14	21	26
• Reduce Hardware Costs	15%	25%	35%
• Reduce Support Costs	15%	25%	35%
• Improve Thrust to Weight (Liquids)	30%	60%	100%
• Mean Time Between Removal (Mission Life-Reusable)	20	20	20
Spacecraft Propulsion			
• Improve ISP (Chemical/Solar Thermal)	10%	15%	20%
• Improve Mass Fraction	15%	25%	35%
• Improve Thruster Efficiency (Electric)	15%	30%	50%
Tactical Propulsion			
• Improve Delivered Energy	3%	7%	15%
• Improve Mass Fraction (Without TVC/Throttling)	2%	5%	10%
• Improve Mass Fraction (With TVC/Throttling)	10%	20%	30%

IHPRPT GOALS
(Continued)
Issues

Boost and Orbit Transfer

- Boost and Orbit Transfer Isp goal represents a combination of cryogenic, hydrocarbon, solid, and hybrid improvements at their own respective levels

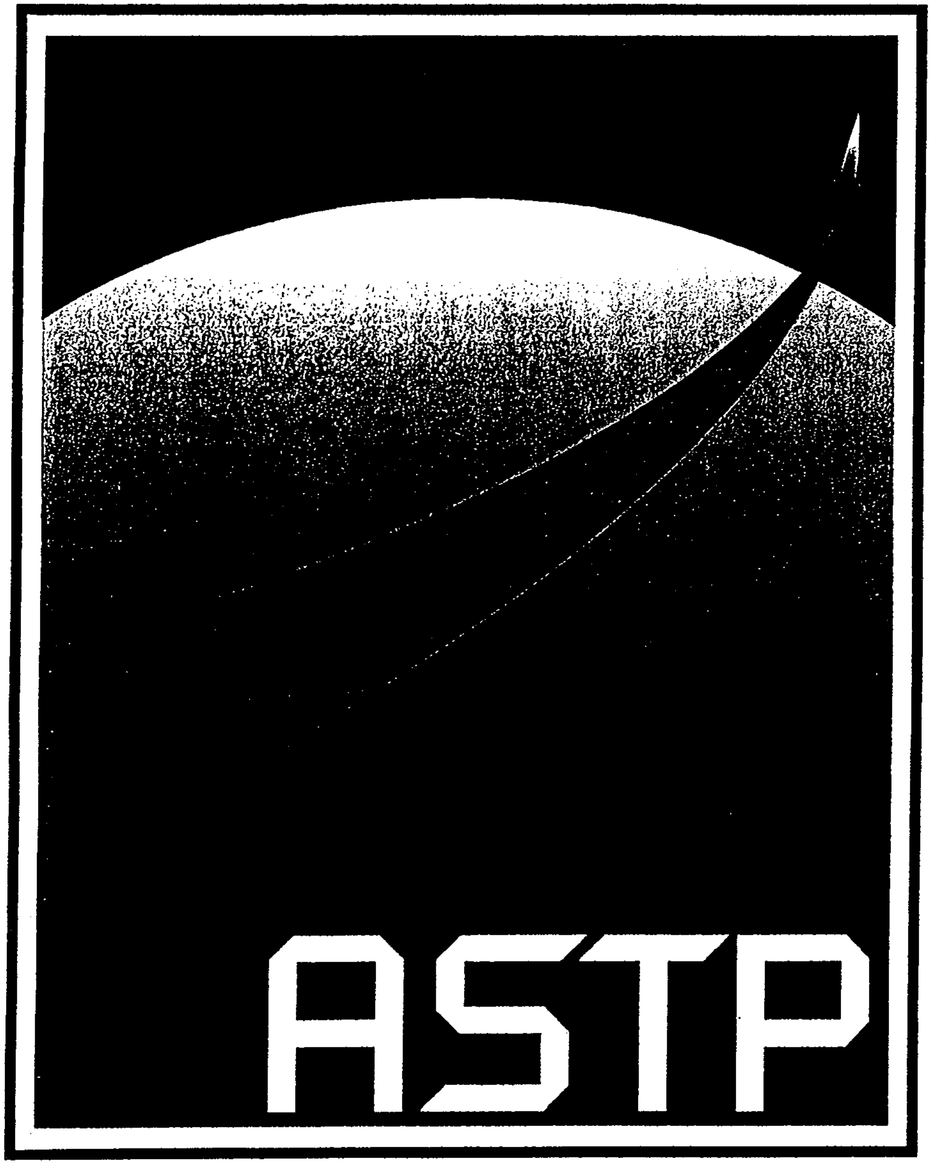
Technology	Baseline	2000	2005	2010
• Cryogenic Engine	450 sec	1%	2%	3%
• Hydrocarbon Engine	263 sec	13%	15%	17%
• Solid Motor	227 sec	7%	10%	13%
• Hybrid Motor	273 sec	8%	11%	15%

- Strategic boost will only work performance goals
- Support Costs also include demilitarization costs and disposal costs

Spacecraft

- Improve mass fraction

  Wet mass fraction = (propulsion system + propellant) wt / (satellite bus + propellant) wt.



Advanced Space Transportation Program

Status

7-17-96

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Advanced Space Transportation Technology Program

Background

- **Tenets**
  - Space transportation is the foundation that enables the Nation's future in space
  - Space transportation is critical for America's competitive position in the international marketplace
  - MSFC will focus space transportation in order to accomplish NASA's Strategic Plan
  - There is no new money in the NASA budget—we must make and implement tough decisions to find resources from within

- **Primary Focus**
  - Low-Cost Reusable Propulsion Technology
  - Small Launcher Technology
  - Space Transfer Technology

- **Implementation of the plan in partnership with industry, academia, and other agencies**

Advanced Space Transportation Technology Program

The Need

Space Transportation is like the point of an inverted pyramid, it enables everything else

Launch cost limits NASA's ability to conduct Earth and space science and limits commercial launch services from competing effectively with foreign launch services

- **Transportation costs account for about 25 percent of NASA's FY1997 budget**
- **Earth and space science spacecraft are becoming smaller and cheaper, driving the need for lower launch cost**

ASTP Turbomachinery Technology Plan

Objective

- **Develop a turbomachinery technology plan to support the Advanced Space Transportation Program**

Motivation

- **Need to lower development cost and time for engine systems while expanding propulsion system capabilities and applications**
- **Turbomachinery characteristics**
  - 25–30 percent of engine weight and cost
  - Longest lead time of engine subcomponent
  - Approximately 40 percent of SSME failures due to turbomachinery

Need comprehensive Turbomachinery Technology Plan to support ASTP

ASTP Turbomachinery Technology Plan

Approach

- Formed co-located turbomachinery team of hardware and discipline specialists
- Derived turbomachinery requirements from NASA space transportation strategies
- Obtained input from industry
- Obtained input from MSFC S&E and PD organizations
- Reviewed NASA turbomachinery activities currently supporting the Space Transportation Plan
- Reviewed IHPRPT and other pertinent turbomachinery activities
- Identified additional required tasks
- Integrated tasks and activities into a cohesive, focused effort to support the Advanced Space Transportation Plan

ASTP Turbomachinery Technology Plan

Strategies/Turbomachinery Technology Requirements

Advanced Space Transportation Strategies

- Enable small payload transportation
- High performance reusable (Reusable Launch Vehicle, RLV)
- Revitalize ETO (Rocket Based Combined Cycle (RBCC))
- Low-cost/high efficiency orbit transfer (RLV orbit transfer)
- Low-cost exploration (Nuclear thermal propulsion)

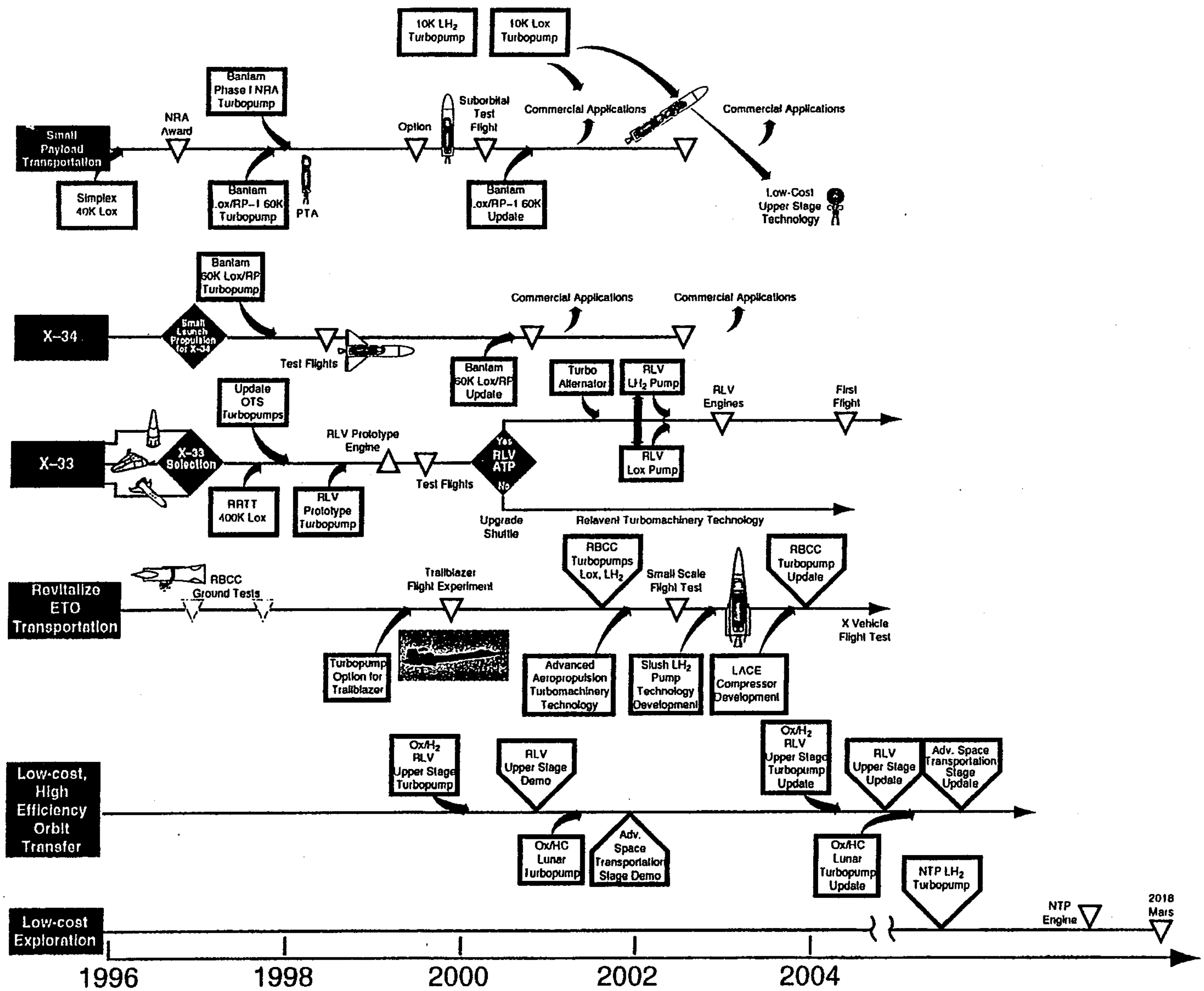
Turbomachinery Technology Requirements

- Low-cost, simple, robust, ease of manufacture, operable
- Low weight, high performance, reliability, long life, low operations
- Reliability, long life, low operations cost, throttleable, quick start, no chill down
- Low-cost, performance, low weight
- Long life bearings, high temperature materials, throttleable

Issues—Cost, weight, performance, life/reusability, and operability

ASTP Turbomachinery Technology Plan

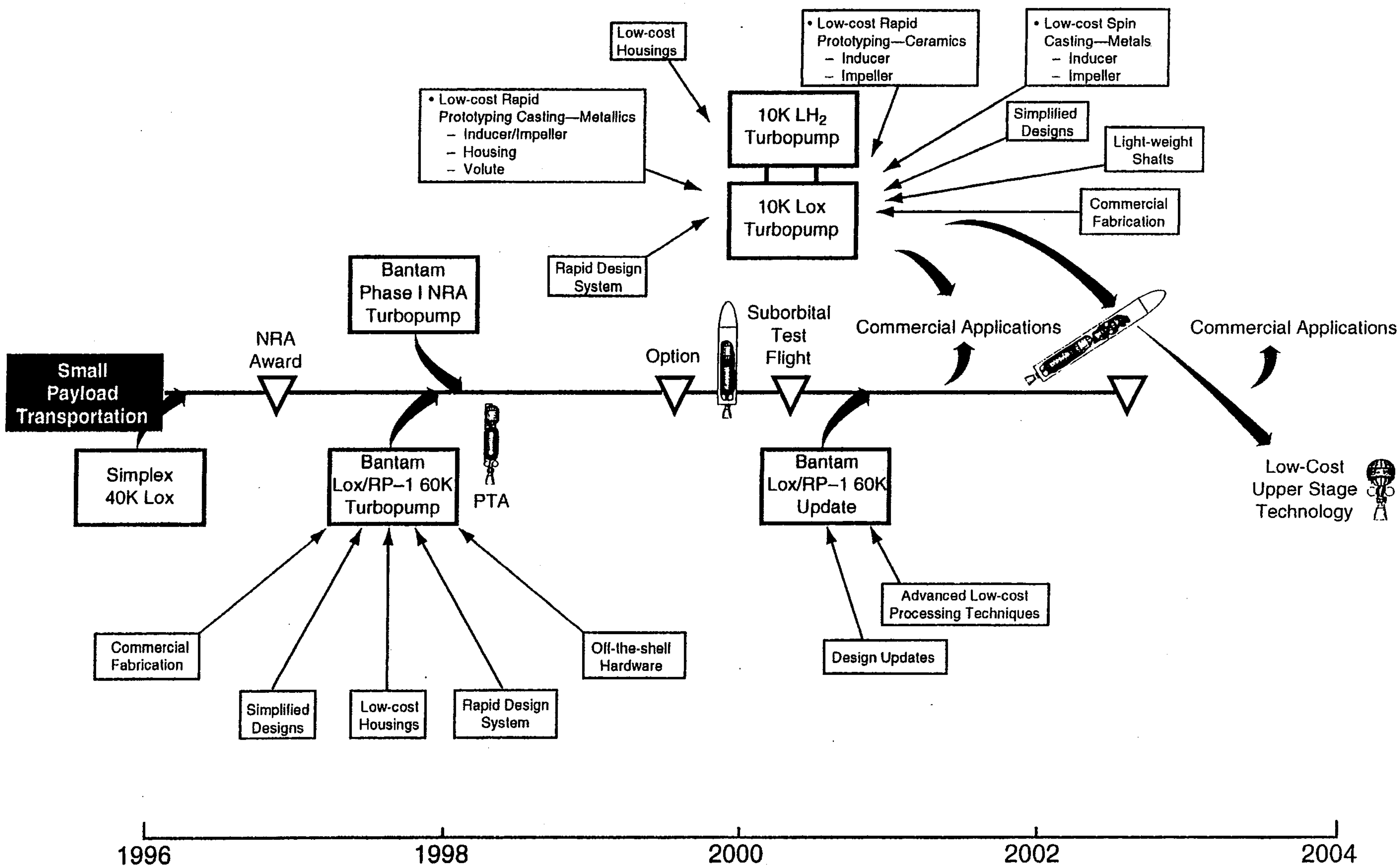
AST Technology Road Map



ASTP—1825

ASTP Turbomachinery Technology Plan

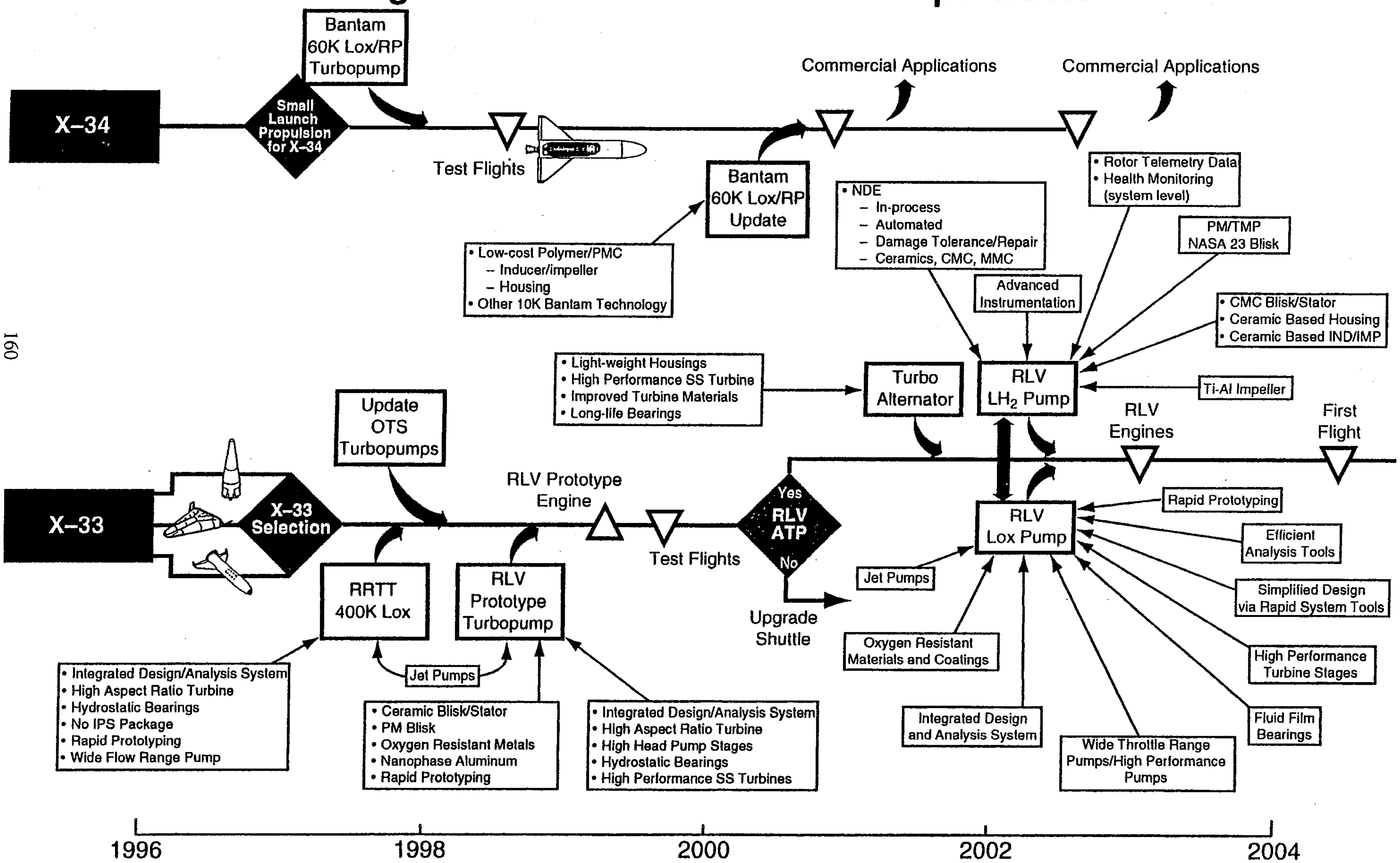
Small Payload Transportation



ASTP—1825

ASTP Turbomachinery Technology Plan

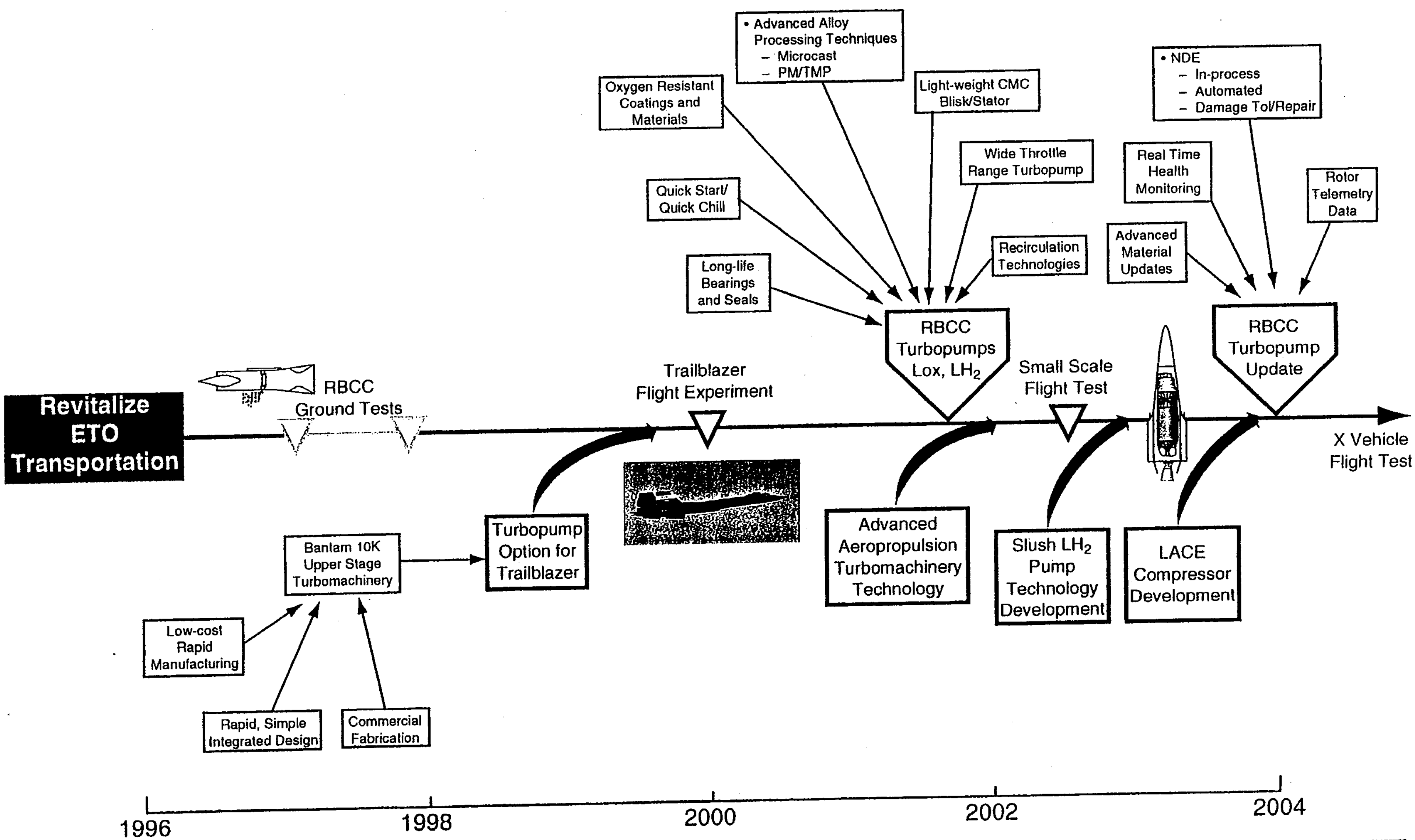
High-Performance Reusable Transportation



ASTP—1826

ASTP Turbomachinery Technology Plan

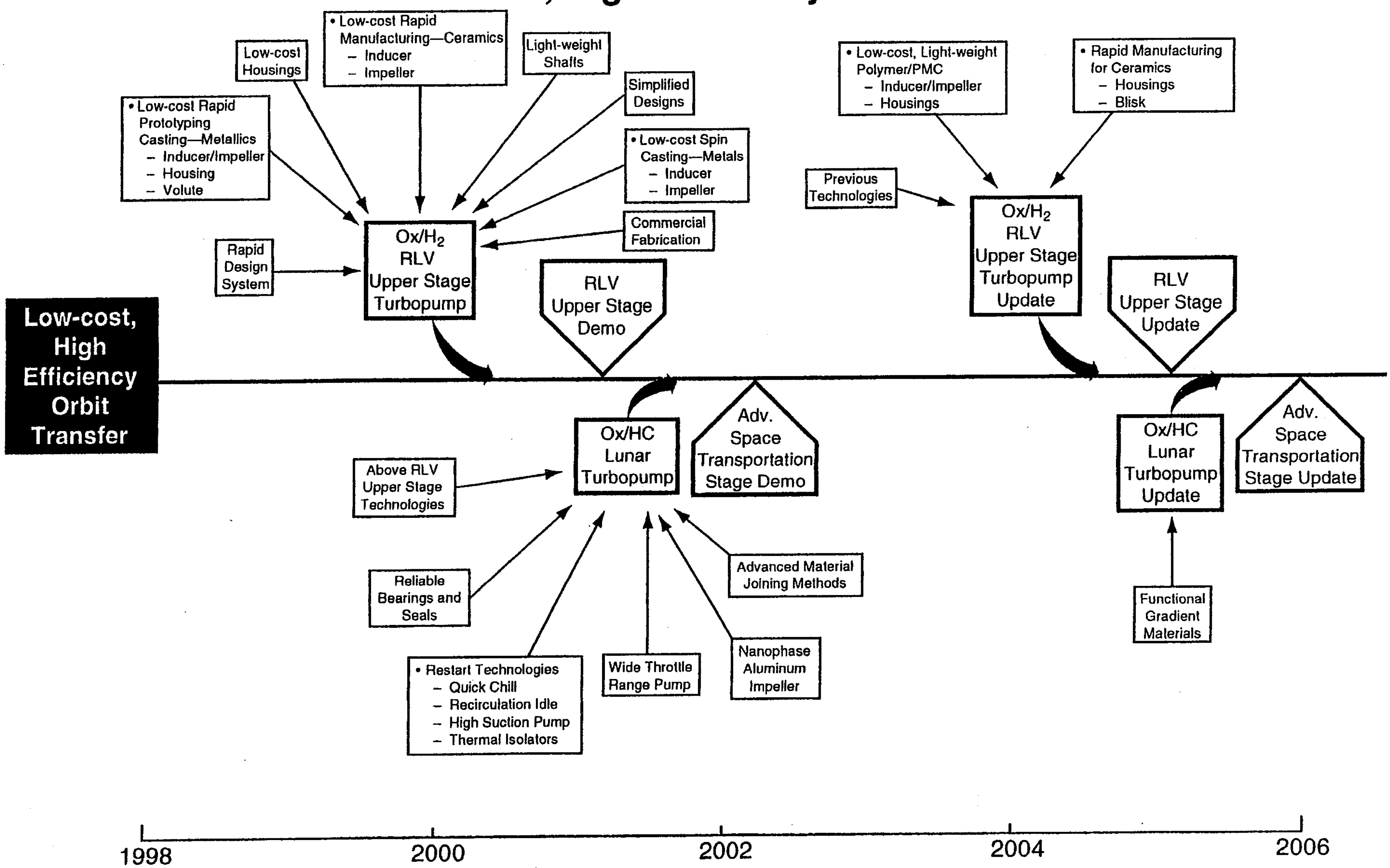
Revitalize ETO Transportation



ASTP—1827

ASTP Turbomachinery Technology Plan

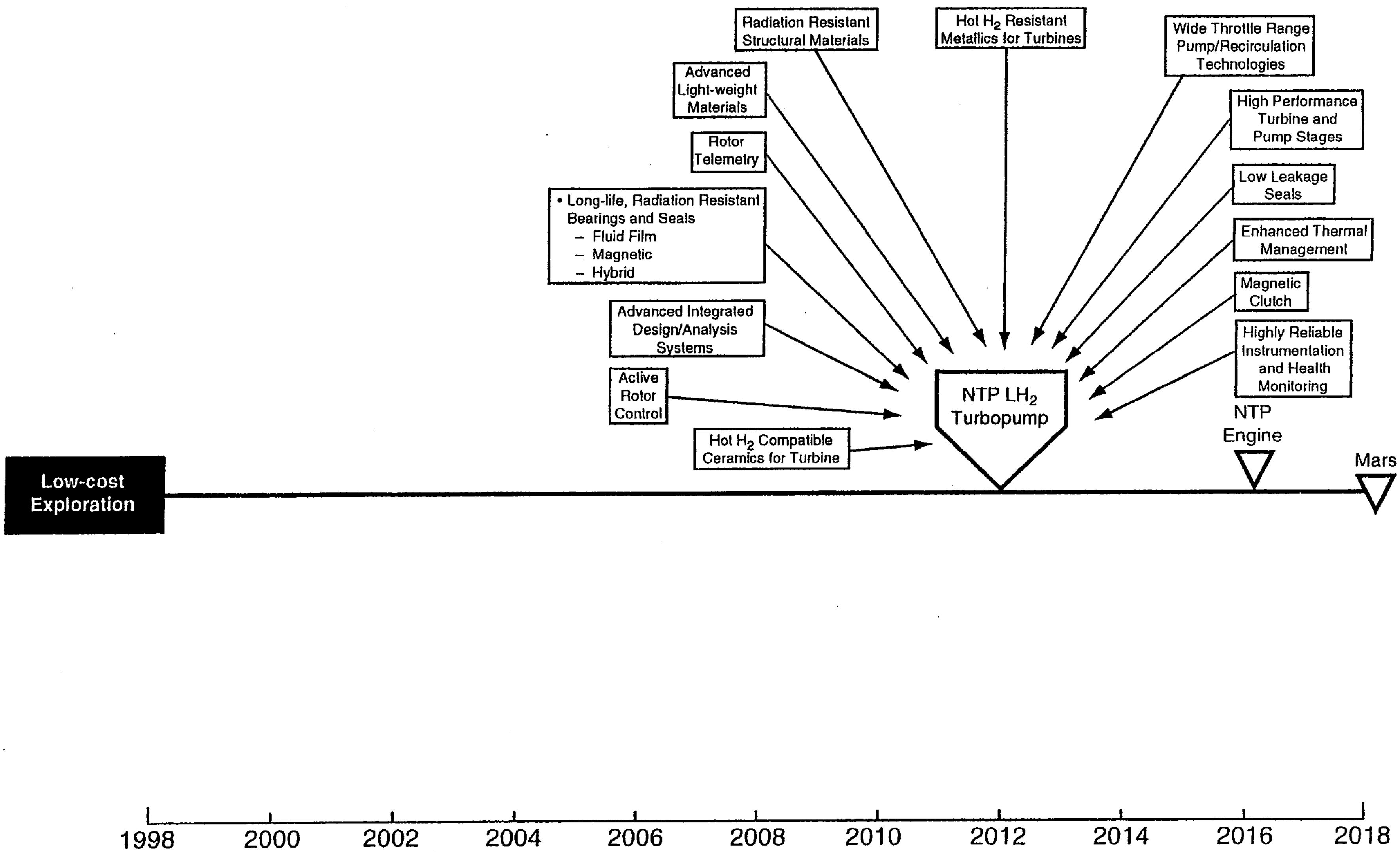
Low-cost, High Efficiency Orbit Transfer



ASTP—1828

ASTP Turbomachinery Technology Plan

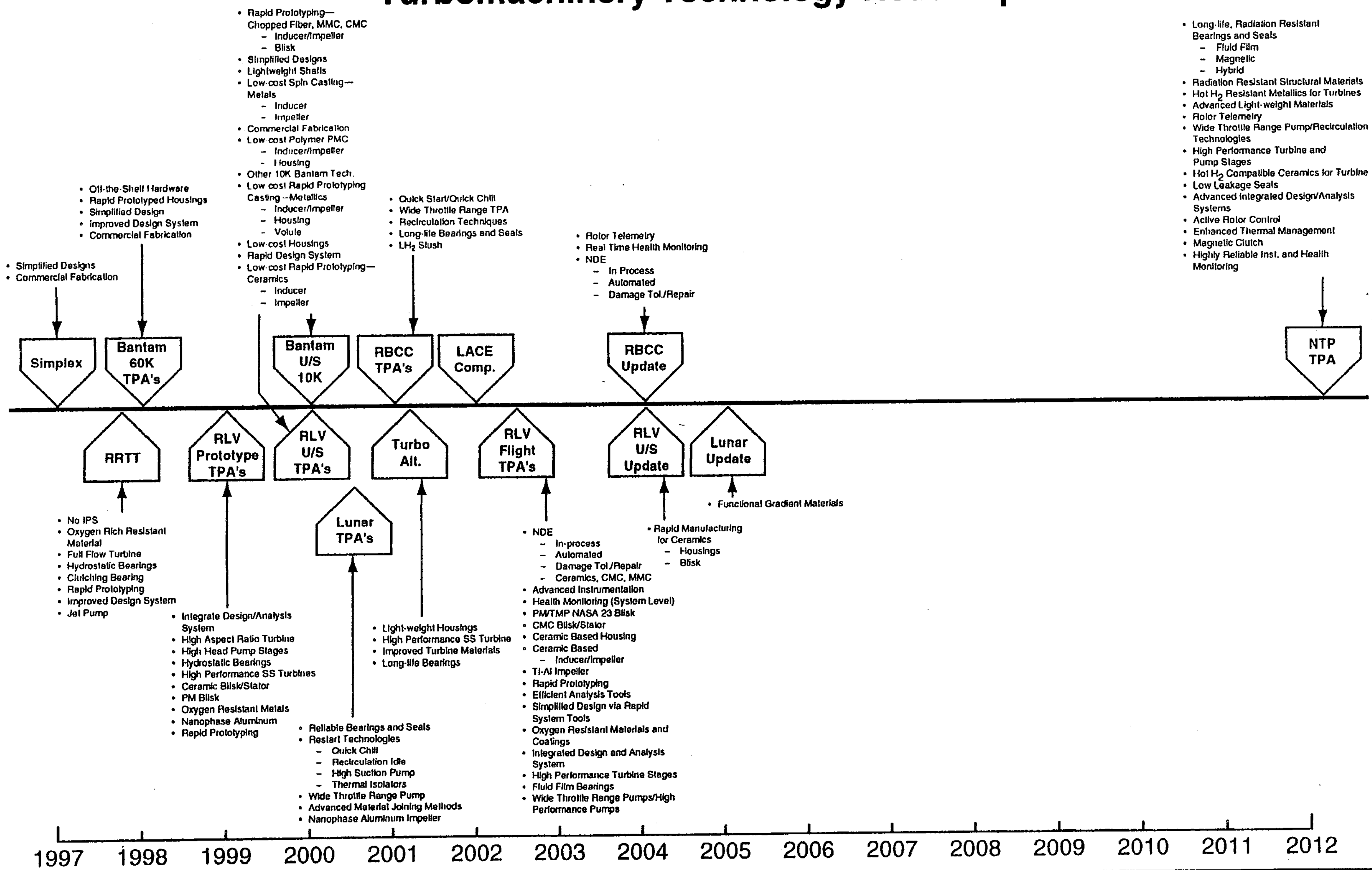
Low-cost Exploration



ASTP—1829

ASTP Turbomachinery Technology Plan

Turbomachinery Technology Roadmap



ASTP—1830